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Waveform Envelope Method to Detect Point on Wave initiation of Voltage Sag

N. N. Jangle
Department of Electrical Engineering
K.K.Wagh Institution of Engineering Education & Research, Nashik

A. M. Jain
Department of Electrical Engineering
K.K.Wagh Institution of Engineering Education & Research, Nashik

B. E. Kushare
Department of Electrical Engineering
K.K.Wagh Institution of Engineering Education & Research, Nashik

Abstract

This paper presents an algorithm for detection and characterization of voltage sag on transmission and distribution lines using Waveform envelope Method. Voltage sag magnitude and duration are two commonly used characteristics of voltage sag. These two characteristics can be obtained by using RMS voltage method. But the other characteristics of voltage sag like point on wave and phase angle jump are not clear from RMS voltage calculation as it uses one or half wave window. In this paper RMS voltage method and discrete wavelet transform method is used to calculate voltage sag magnitude of voltage sag disturbance from fundamental 50 Hz frequency. Point on wave initiation is a characteristic that can not be identified from RMS waveform. So, to detect Point on wave initiation sinusoidal voltage equation is used with discrete wavelet transform. As alternating waveform is not always ideal but it is disturbed due to different load conditions on system, Waveform envelope algorithm is simulated to detect point on wave initiation in MATLAB simulink and the results are presented at various magnitudes and Point on Wave initiations.
Keywords: Power Quality, Point on Wave Initiation, Voltage Sag, Discrete Wavelet Transform, Waveform Envelope

I. INTRODUCTION

Power quality has become an important issue over the past several years [1]. One of most important power quality issues on transmission and distribution lines is the voltage sag. It causes severe effects to end users [1, 2]. In general, sag characteristics, e.g. magnitude and duration are typically determined using an RMS envelope. For some types of equipments an accurate determination of fault initiation and clearing time is needed to properly determine other characteristics such as Point on Wave, phase angle jump to verify proper operation of equipment [2, 3]. Accurate time localization or Point on Wave initiation of sag disturbance is one of the important first steps in accurately determining some of these additional parameters. IEEE standard 1346, 1998 states that information about phase shift and Point on Wave values is not typically available in sag environment data. Therefore for compatibility evaluation it is recommended that phase shift and Point on Wave initiation should not considered. Reference [3], particularly describes that the behavior of contactor not only depends on magnitude and duration of voltage sag but also the Point on Wave initiation where voltage sag occurs. This paper describes the definition of voltage sag characteristics, algorithm for characterization of voltage sag and results by using MATLAB 7.1 software.

II. VOLTAGE SAG CHARACTERISTICS

The voltage sag is defined by IEEE Standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, is a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage. Typical values are between 0.1 p.u. and 0.9 p.u. and typical fault clearing time ranges from three to thirty cycles Another definition as given in IEEE Std. 1159, 3.1.73 is A variation of the RMS value of the voltage from nominal voltage for a time greater than 0.5 cycles of the power frequency but less than or equal to 1 minute. This paper presents an algorithm, which will give the characteristics of voltage sag using DISCRETE WAVELET TRANSFORM with RMS and instantaneous waveform. The algorithm is tested with the waveforms obtained from simulation model of voltage sag generator, developed in MATLAB 7.1, using SymPowerSystem toolbox. Following are the important characteristics to which equipments are sensitive [1-4].

- Voltage Sag Magnitude
- Duration
- Point on wave
- Missing Voltage
- Phase-Angle Jump

III. VOLTAGE SAG GENERATOR MODEL

A simulation model figure 3.1 is developed to generate voltage sag. To obtain the voltage sag three-phase single line to ground fault is created. The voltage sag of magnitudes 10, 20, 30....up to 80 % and Point on Wave initiation from 0 degree to 90 degree with the steps of 15 degree differences is generated in the simulation model.

From the simulation model RMS and instantaneous waveforms are captured across the load. By using RMS waveform voltage sag magnitude and duration are calculated according definition mentioned in the IEEE standard 1159-1998. The magnitude is calculated as the percentage of the remaining voltage during the event and the duration is by looking for RMS voltage levels that drops below a specified threshold. A software program is developed to detect point on wave initiation at voltage sag magnitudes 0, 10, 20, …..80% and at 0, 15,30,…..90 degree point on wave initiation using DISCRETE WAVELET TRANSFORM.

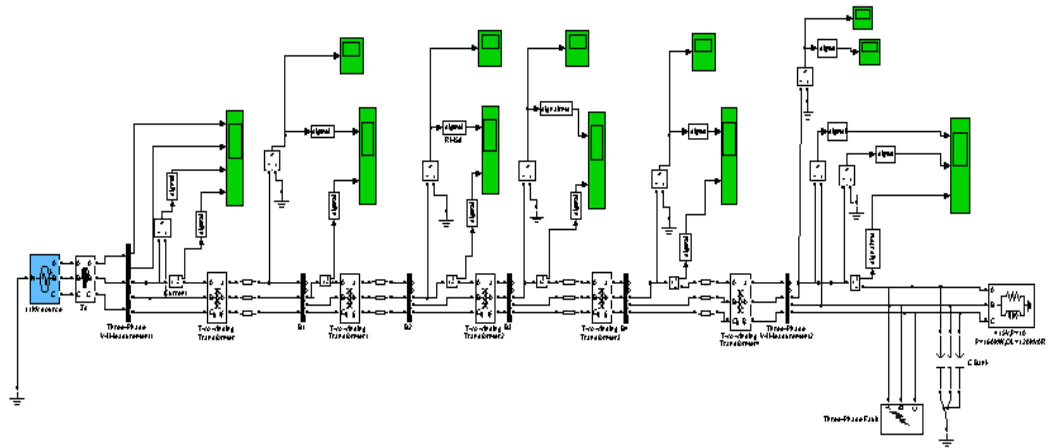

Fig. 1: Voltage sag Generator model

IV. ALGORITHM FOR VOLTAGE SAG MAGNITUDE AND DURATION

Considering one cycle window before RMS voltage start, to detect start of voltage sag using DWT (Discrete Wavelet Transform) Daubechies wavelet (db4) is used. This method is capable to identify start and stop times close to 100% of the disturbance analyzed, and it produces results as good as or better than those obtained from RMS voltage method. -The Discrete wavelet transform procedure is used to determine the Point-on-wave initiation as it detects sag start. Discrete Wavelet Transform approach is explained to detect start and end of voltage sag in [5]

Following algorithm is implemented on the waveform obtained from simulation to detect magnitude and duration of the voltage sag.

Steps of the algorithm for voltage sag magnitude and duration.

- Step 1 Start
- Step 2 Get instantaneous sag waveform data, instantaneous ideal waveform data, and RMS waveform data as input from workspace.
- Step 3 Find maximum voltage of RMS waveform (vmax).
- Step 4 Find maximum voltage of ideal instantaneous waveform (Vmax).
- Step 5 Find pre-fault RMS voltage
- Step 6 Find minimum voltage of RMS waveform i.e. 'Magnitude of remaining voltage'.
- Step 8 Calculate Missing voltages.
- Step 9 Find Start of voltage sag by considering fall of RMS voltage by 0.9pu.
- Step 10 Find End of voltage sag by considering rise of RMS voltage by 0.9pu.
- Step 11 Calculate duration of Voltage Sag.
- Step 12 Apply Discrete Wavelet Transform db4 at scale 1 to the instantaneous sag waveform and get the WTC data.
- Step 13 Calculate the Threshold (THR) by de-noising the Wavelet transform coefficients (WTC's) obtained in Step 12.
- Step 14 Find the de-noised WTC data of data vector P of length N that violets the Threshold.
- Step 15 Search for the point (S) that corresponds to the Sag Start Time. To narrow the search, first find the RMS sag start time of the voltage sag. Then, define a search window extending from one cycle before the RMS start time to the RMS start time.
- Step 16 To find the Sag End Time, start from S, which corresponds to nth element P (n) that fall outside the end time threshold which may be different from the start time Threshold.
- Step 17 Calculate Duration of Voltage sag using DISCRETE WAVELET TRANSFORM Start and End Time.

From steps implemented in above algorithm it is observed that voltage sag magnitude and duration can be easily detected by using RMS plot and Discrete Wavelet Transform Db4 wavelet as shown in figure 4.4.

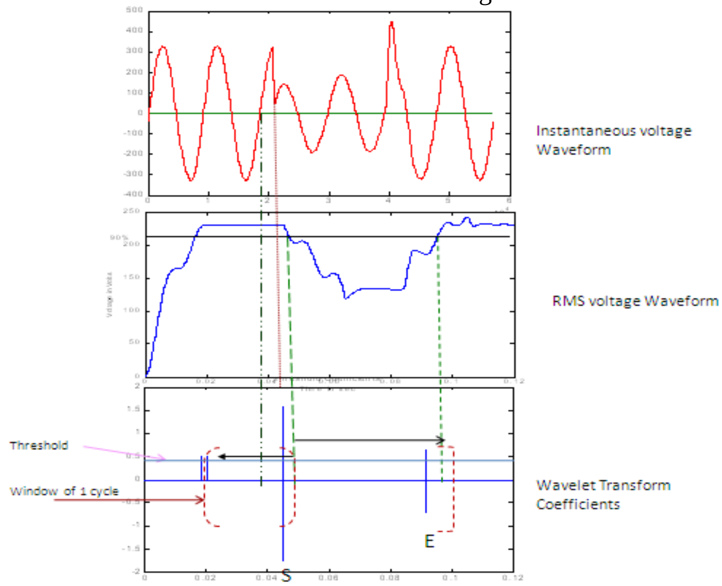

Fig. 2: DWT results after denoising and thresholding

V. WAVEFORM ENVELOPE METHOD

Point on wave initiation can also be detected by direct comparing ideal voltage waveform and disturbed waveform.
But results will not be accurate if the ideal waveform and sag waveform deviate at any instant. It is possible to detect these characteristics if the waveform envelope approach explained in [5] is implemented in algorithm.

In IEC Standard 61000-4-30: 10% and 5% waveform envelopes are used for the identification of point of initiation values and only the 10% waveform envelop for the identification of point-of-ending values. The reason for using only the 10% waveform envelope for the identification of point-of-ending values is that ‘most sags do not recover to within 5% in the data set intervals.

The waveform envelope method given in reference [5], is an alternative approach that attempts to determine the sag start and end times from the instantaneous phase voltage waveform. First, for a given sag event, the pre-fault steady state voltage is considered to be the “ideal” voltage. Next, two sets of additional waveforms, one ±10% of the ideal voltage and one at ±5%, are calculated to form an “envelope” around the ideal voltage waveform. If there is no disturbance, the phase voltage stays within the envelopes, and no event is detected. In the presence of sag, however, the voltage falls outside of one or both envelopes, and the event is detected.

In this paper the same procedure with ±5 % envelope is used to detect point-on-wave initiation. The Algorithm is summarized in VI.

VI. ALGORITHM FOR WAVEFORM ENVELOPE METHOD

Fundamental equation uses a basic equation of Alternating voltage i.e.

$$Vi = Vm \sin\theta \qquad (6.1)$$

Where Vi = instantaneous voltage
Vm= peak voltage
θ = ωt =pahse angle,
ω=2 Πf = angular frequency

So from this fundamental equation, Point-on-wave initiation is determined with assumption that Vi is voltage at which voltage sag start, Vm is the peak voltage of the ideal waveform.

$$\text{Point-on-wave initiation i.e. } \theta = Sin^{-1}\frac{Vi}{Vm} \qquad (6.2)$$

Figure 3 shows the ±5% envelope of instantaneous voltage.

1) The event is detected when ideal waveform is deviated from the voltage sag waveform.
2) Once the event is detected it is checked that the event time and magnitude is within the 5 % envelope of ideal waveform at every 15˚ difference.
3) If it is within 5% envelope then the procedure is continued otherwise the previous angle is declared as the point-on-wave initiation using fundamental equation of voltage

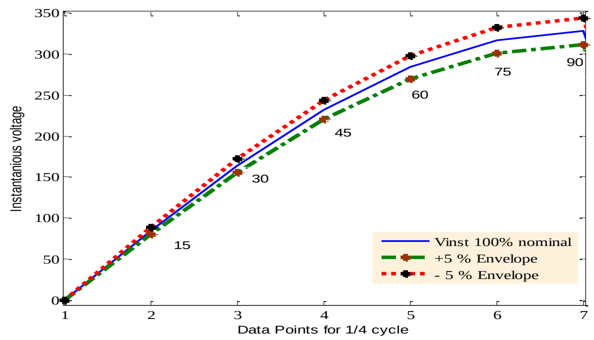

Fig. 3: ± 5 % Envelope of Instantaneous voltage waveform

Table - 1
Point on wave initiation of voltage sag using Waveform envelope method

Voltage sag Magnitude	Actual Point on Wave initiation	Duration_Of_Sag_By_RMS	Duration_Of_Sag_By_DWT	Point on wave initiation By_WaveFormEnvelop_Method
%	Degree	Sec	Sec	Degree
15.5337	0	0.0524	0.0401	0.0000
15.5166	15	0.0524	0.0438	15.0000
15.4797	30	0.0523	0.0431	30.0000
15.4725	45	0.0520	0.0422	45.0000
15.5768	60	0.0515	0.0419	60.0000
15.8876	75	0.0509	0.0404	74.9847
15.5327	90	0.0498	0.0405	89.4664
19.9723	0	0.0522	0.0442	0.0000
19.9878	15	0.0522	0.0439	15.0000
20.0477	30	0.0521	0.0451	30.0000
20.1891	45	0.0518	0.0420	45.0000
20.4716	60	0.0513	0.0416	60.0000
20.9592	75	0.0505	0.0400	74.9728
20.0832	90	0.0494	0.0401	89.3695
30.0391	0	0.0515	0.0442	0.0000
30.0853	15	0.0515	0.0439	15.0000
30.2386	30	0.0514	0.0432	30.0000
30.5253	45	0.0511	0.0418	45.0000
30.9748	60	0.0506	0.0412	60.0000
30.5614	75	0.0498	0.0400	74.9728
29.1159	90	0.0487	0.0391	89.3695
40.3547	0	0.0508	0.0435	0.0000
40.3982	15	0.0508	0.0444	15.0000
40.5496	30	0.0507	0.0415	30.0000
40.8308	45	0.0504	0.0411	45.0000
41.2665	60	0.0499	0.0405	60.0000
39.2506	75	0.0491	0.0398	74.9728
37.4404	90	0.0479	0.0392	89.3695
49.1677	0	0.0501	0.0432	0.0000
49.2003	15	0.0501	0.0431	15.0000
49.3186	30	0.0500	0.0439	30.0000
49.5441	45	0.0498	0.0417	45.0000
49.1949	60	0.0492	0.0406	60.0000
46.3287	75	0.0485	0.0399	74.8438
44.3292	90	0.0472	0.0422	87.7647
59.6076	0	0.0492	0.0193	0.0000
59.6228	15	0.0492	0.0392	15.0000
59.6951	30	0.0491	0.0414	30.0000
59.8376	45	0.0489	0.0403	45.0000
57.6892	60	0.0484	0.0397	60.0000
54.6845	75	0.0476	0.0388	74.9728

52.6349	*90*	*0.0017*	*0.0390*	*89.3695*
70.1844	*0*	*0.0478*	*0.0393*	*0.0000*
69.8920	*15*	*0.0478*	*0.0520*	*15.0000*
69.3564	*30*	*0.0478*	*0.0425*	*30.0000*
69.1209	*45*	*0.0476*	*0.0399*	*45.0000*
66.6308	*60*	*0.0471*	*0.0491*	*60.0000*
63.7376	*75*	*0.0462*	*0.0409*	*74.9847*
61.8657	*90*	*0.0406*	*0.0244*	*89.4664*
79.7741	*0*	*0.0019*	*0.0367*	*0.0000*
79.5191	*15*	*0.0022*	*0.0363*	*15.0000*
78.9733	*30*	*0.0027*	*0.0368*	*30.0000*
78.5131	*45*	*0.0029*	*0.0374*	*45.0000*
76.7085	*60*	*0.0024*	*0.0370*	*60.0000*
74.3092	*75*	*0.0318*	*0.0283*	*74.9847*
72.8989	*90*	*0.0313*	*0.0437*	*89.4664*

VII. CONCLUSION

Magnitude, duration point on wave initiation, point on wave recovery, phase angle jump are the characteristics of voltage sag. Out of these characteristics magnitude and duration characteristics can be calculated by using RMS voltage and Descrete Wavelet Transform method. The important characteristics voltage sag is point on wave initiation which can not be identified from RMS waveform. To calculate this characteristic only sinusoidal waveform is required. As the sinusoidal waveform of supply is not ideal it gets fluctuated due to many reasons waveform envelope method is implemented in this paper. This method gives near to accurate values of point on wave initiation at various magnitudes of voltage sag.

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